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TECHNOLOGY AND PHYSICS OF INFRARED AND POINT CONTACT DIODES

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Background work for this contract performed by this laboratory has shown that the tunneling characteristics of junctions formed by a very thin dielectric layer surrounded by two metals is independent of frequency (from DC through 10μ wavelength). These junctions may be formed by a point contact on a lightly

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oxidized metal surface. Work done this period involved principally relatively large evaporated structures with measurements in the microwave and far infrared regions where the circuit parameters do not mask the junction characteristics. Calculations have been performed which qualitatively resemble junction, antenna and associated parasitic parameters. A preliminary survey of far infrared incoherent sources has been conducted and such a source is being procured. The microelectronics group at Lincoln Laboratory has worked on optimizing several fabrication procedures of the printed structures. Three new structures have been designed. Informal discussions with Perkin Elmer Optical Products Groups's Research Laboratory have resulted in a plan to investigate oxide growth and characteristics of the resulting dielectric layer.

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Background work for this contract performed by this laboratory has shown that the tunneling characteristics of junctions formed by a very thin dielectric layer surrounded by two metals is independent of frequency (from DC through 10μ wavelength.) These junctions may be formed by a point contact on a lightly oxidized metal surface or by metal evaporation on such an oxidized metal surface. Work done this period involved principally relatively large evaporated structures with measurements in the microwave and far infrared regions where the circuit parameters do not mask the junction characteristics. Calculations have been performed which qualitatively resemble junction, antenna and associated parasitic parameters. A preliminary survey of far infrared incoherent sources has been conducted and such a source is being procured. The microelectronics group at Lincoln Laboratory has worked on optimizing several fabrication procedures of the printed structures. Three new structures have been designed. Informal discussions with Perkin Elmer Optical Products Group's Research Laboratory have resulted in a plan to investigate oxide growth and characteristics of the resulting dielectric layer.

Technology and Physics of Infrared and Point Contact Diodes

I. Introduction

Preliminary work in this laboratory[1] has determined that tunneling characteristics of metal-dielectric-metal (MDM) tunneling junctions across a thin dielectric layer is independent of the frequency. We have performed a number of evaporations and measured the resultant diodes in an attempt to understand the physics of dielectric layer. . This is an important part of our investigation of the characteristics of dielectrics that may be used in tunneling junctions. Since areas are much larger than state-of-the art, our measurements will correspondingly be made at 10 to 1000 GHz. Calculations described later in this report show performance of the receiving and detecting element as a function of the fabrication parameters and including the effects of strong frequency dependence of the circuit elements. Early experimental work has been conducted at microwave and far infrared because performance of easily fabricated structures is not far into the RC roll off region. At these frequencies much can be learned about junction stability and spectroscopy of dopants in a very thin oxide layer, and more accurate values can be obtained for the circuit constants. We have conducted a preliminary survey of far infrared incoherant sources and are procuring such a source. Collaboration with the microelectronics group at Lincoln Laboratory has been increased with three new structures designed and several fabrication constants being optimized. Contacts with Perkin Elmer Optical Products Group's Research Laboratory have resulted in a plan to investigate oxide growth and characteristics of the resulting dielectric layer.

2. Diodes fabricated by evaporation through a mask

In order to facilitate testing of different materials and fabrication procedures, we have made a number of relatively large area junctions by evaporation through a mask. An etched metal mask has been procured. (See Fig. 1). The design is such that when an evaporation is made the substrate may be oxidized, then rotated 90° in its holder and a second evaporation will overlap each narrow oxidized metal strip with another, thus simultaneously forming four tunneling barriers.

Work with aluminum-aluminum oxide-lead barriers showed that with short oxidation times at relatively low pressures it is possible to achieve oxide thickness under 10 Å but that exposure to air increased the barrier resistance an order of magnitude in the first few minutes and ultimately to values above a megohm. Since this change did not take place in the vacuum, and the metal layer (about 5000 Å) overlying the junction is rather too thick for penetration, the process must proceed from the edges. Additional work has been done with aluminum as the top metal as well as the bottom. The same changes were noted. When silicon monoxide was evaporated over the junction before breaking vacuum, the change could be reduced to a few percent per day. It is likely that even greater stabilization may be possible either by varying the thickness of silicon monoxide or depositing it from two points to assure covering the exposed edges of the junction, which might otherwise be shadowed, or by using a different protective material.

The junctions appear quite non-linear at 0.1 to 0.2 V bias. A corresponding non-linearity is observed when the junctions are driven at 10 MHz. Our calculations indicate that these relatively large

area junctions should exhibit about the same non-linearity at X-band and that roll-off should not exclude detecting a signal at 337 μm. Unfortunately we have not yet seen the infrared signal although 10 mw of incident power was available. The microwave signal was barely discernable. The most likely reason is poor coupling into the junction. It is well to recall that these junctions are on the order of 100 square μm as opposed to 0.1 square μm, as is the limit of conventional photolithography.

3. Dielectric Formation

Much consideration has been given to methods of insulator formation since the problems are unique when thicknesses of the order 10 Å are required. As these are less than 10 atom layers and permit essentially no pinholes, self-grown oxides (or possibly nitrides or sulfides) appear to be the most promising approach. Insulators that are evaporated, sputtered or deposited in some other way tend to form small islands and grow to cover the surface. Such layers inherently have pinholes until their thickness is several hundred Å.

4. Calculations

Calculations have been made of the signal to noise ratio (directly related to NEP), rectified power, diode resistance and other operating parameters of an antenna coupled to an MDM junction. The assumed incident power is 1 mw of which is re-radiated and the balance coupled to the tunneling barrier junction. The frequency and barrier dimensions are varied, at a predetermined barrier height and assymmetry factor as well as bias voltage and dielectric constant for a trapezoidal barrier. Tunneling calculations were based on Stratton's theory.[2] The results are summarized in the graphs of Figs. 2,3. The resulting NEP's are about one order of magnitude better than what we have been able to achieve experimentally,yet.

5. Tunneling resonances

In addition to the normal electron tunneling that is the basis for the calculations in paragraph 4 other processes may take place. A tunneling electron may be inelastically scattered by an impurity in the dielectric;[3] the electron loses a certain amount of energy and the impurity molecule is left in an excited state with energy $h\nu$. This process can only occur if the junction is biased with a voltage $V > h\nu/e$. As a result of this, a structure appears in the plot of $\frac{\partial^2 J}{\partial V^2}$ versus the bias voltage, which except for the background, is similar to the infrared spectrum of the impurity molecules in the gas phase. (See Fig. 4). Because of the thermal smearing of the Fermi level of the electrodes, the use of cryogenic temperatures is necessary in order to improve the resolution of the resulting tunneling spectrum. In this way, we have observed tunneling resonances in aluminum-aluminum oxide-aluminum junctions.

This effect can be utilized in different ways. As a spectroscopic tool for chemical analysis it can give information on the impurity content of the dielectric in the tunneling junction. On the other hand, the enhanced non-linearities that result when the junctions are cooled to cryogenic temperatures will improve the performance of the MDM junctions as mixer elements.

6. Non-coherent Far Infrared Sources

Non-coherent far infrared sources tend to be very inefficient. The simplest of such sources being a simple black body with a short wavelength cutoff filter. Almost all of its energy will be shorter wavelength than desired and will be absorbed (or reflected) by the filter. A much more efficient source is a high pressure mercury lamp without pyrex outer jacket.[4] This emits high intensity ultra-violet and behaves as a 5000° far infrared

radiator but at intermediate wavelengths (below about 100 μm) it has greatly decreased intensity. Two such lamps are being procured: General Electric H 100 A4/T and Philips HPK 125 W. These will be used as references in our radiation detection studies.

7. Antenna Designs

Several antenna designs have been built by Lincoln Labs for this project. The latest two consist of: 1) An infrared dipole and tunneling junction connected to a microwave dipole and DC output by a parallel conductor transmission line (Fig. 5); 2) a $\frac{3\lambda}{2}$ infrared dipole with junction and transmission line (Fig. 6).

Shipley (positive) photoresist is used throughout this fabrication, in part because it gives overhanging edges after development, which facilitates the metal separation in a lift off process. Substrates are sapphire on which resist is exposed and developed, leaving half dipole and half of a transmission line as uncovered sapphire. After chrome and nickel evaporation, the resist is stripped removing most of the metal and leaving the half pattern. The subsequent air oxidation may be modified by a later plasma operation. A second resist is exposed with the other half pattern, and for reduced resistance some of the first half pattern is also overcoated. A plasma cleaning step removes residual resist and may modify the existing junction oxide. Chrome and gold are evaporated and the resist is again stripped leaving the desired final pattern.

8. Antenna Trimming

In another phase of the experiment the output of a far infrared HCN laser was coupled to a printed element with an integrated dipole antenna. The laser could be made to operate in either 337 μm or 311 μm transitions. The resulting rectified signals from both

wavelengths were compared and it was found that sometimes one wavelength was coupled better than the other as a result of a different antenna mismatching. Changing the antenna length would modify the antenna impedance affecting the amount of infrared power actually reaching the non-linear junction. It was found that when trimming the antenna length with a diamond scribe in small steps, the rectified signal increased initially, reached a maximum and finally decreased for shorter dipole lengths. For 337 μm and 311 μm these maxima were correspondingly different.

9. Rotation of printed antenna elements in an infrared field.

A mount for printed diodes has been made which provides contacts to the outputs and permits rotation of the antenna. This rotation is either about the dipole element itself or about the feed lines (on the surface but perpendicular to the dipole elements); at all times the dipole remains properly oriented in the polarized laser field. Rotation about the feed lines of the $\frac{3\lambda}{2}$ element gives a large maximum and two very much smaller side lobes. (See Fig. 7). More structures are being fabricated and will be evaluated. Rotation about the antenna elements gives a broad flat maximum with no side lobes. This has been interpreted as increased reflectivity of the underlying sapphire as the angle of incidence approaches 90°. Calculations can be made to fit the data qualitatively (including the effects of the dielectric constant) but no accurate evaluation of the effects of reflection from the backside of the sapphire have yet been made.

10. Oxide Studies

In an effort to understand oxide growth mechanisms and means of evaluating thickness and perfection of such dielectric layers,

we have contacted Perkin Elmer Optical Products Group. They have proposed a program to study oxidation rates using ESCA (Electron Spectroscopy for Chemical Analysis) which should also give help in detecting pinholes too small (<30 Å) to see with a field emission source scanning electron microscope. They have also proposed to look for the effect of atmospheric exposure to the surfaces and evaluate metal cleaning techniques preparatory to oxidation. They are prepared to evaluate Lincoln Lab evaporated, and subsequently processed, metal to determine the thickness, uniformity and composition of the barrier in our diodes.

11. Low temperature effects

We are preparing equipment to look for more detail in low temperature effects (1-4° K). Specific objectives of these experiments include, possible negative resistance in superconducting junctions. Also, utilizing the non-linearities existing at low bias (a few mV) in non-superconducting tunneling due to "zero bias anomalies." In conjunction with the small RC of our junction it would considerably improve their rectifying and mixing characteristics in the infrared.

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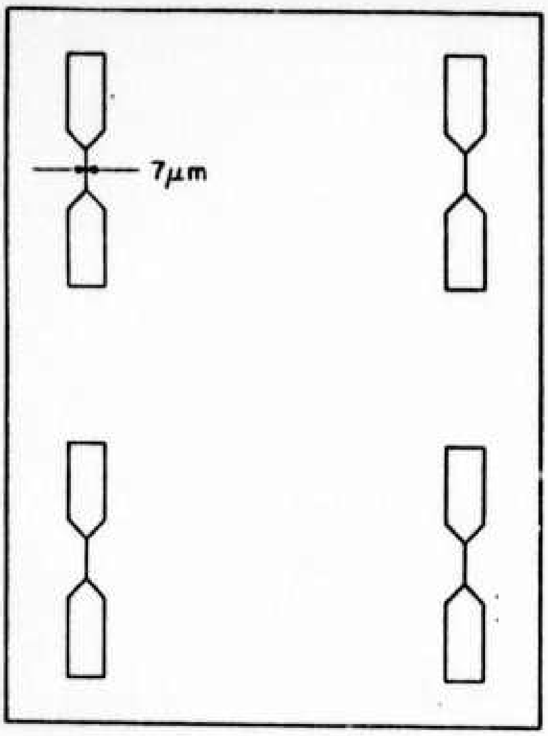

Fig. 1 Layout of Evaporation Mask

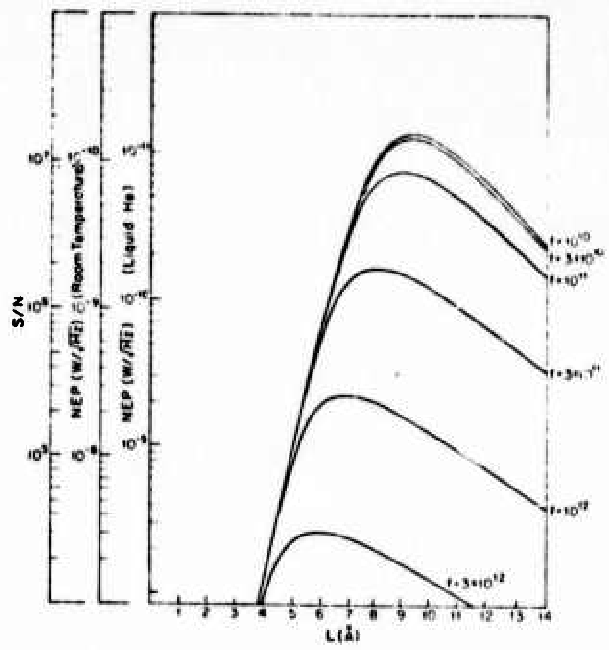

Fig. 2 Typical NEP vs. Barrier Thickness. Junction Area = 1 $(\mu m)^2$

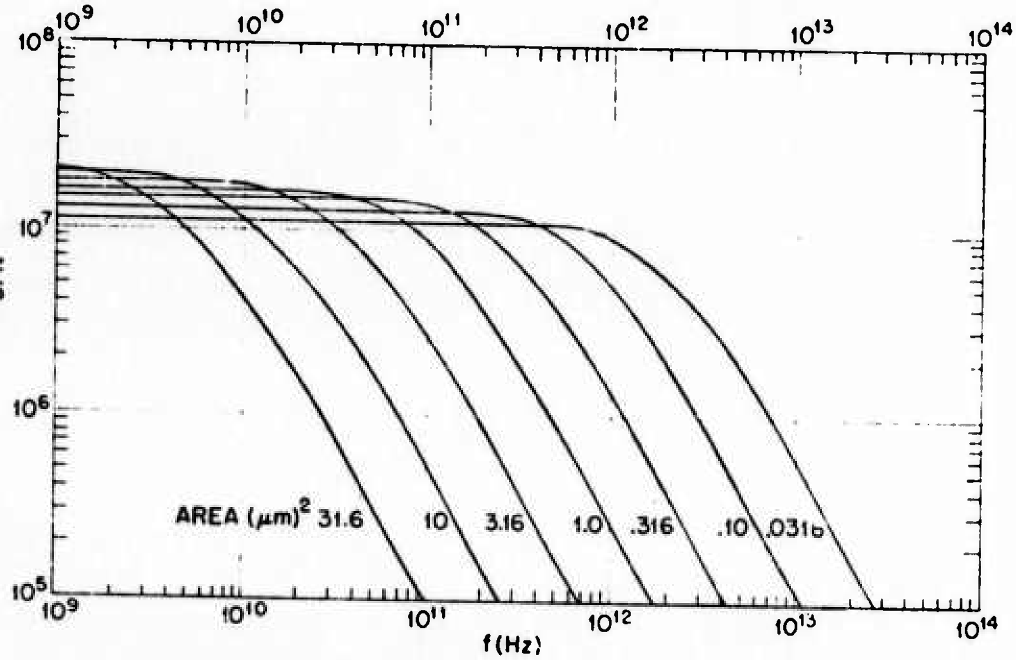

Fig. 3 Array of Maximum Signal to Noise Curves for Various Contact Areas.

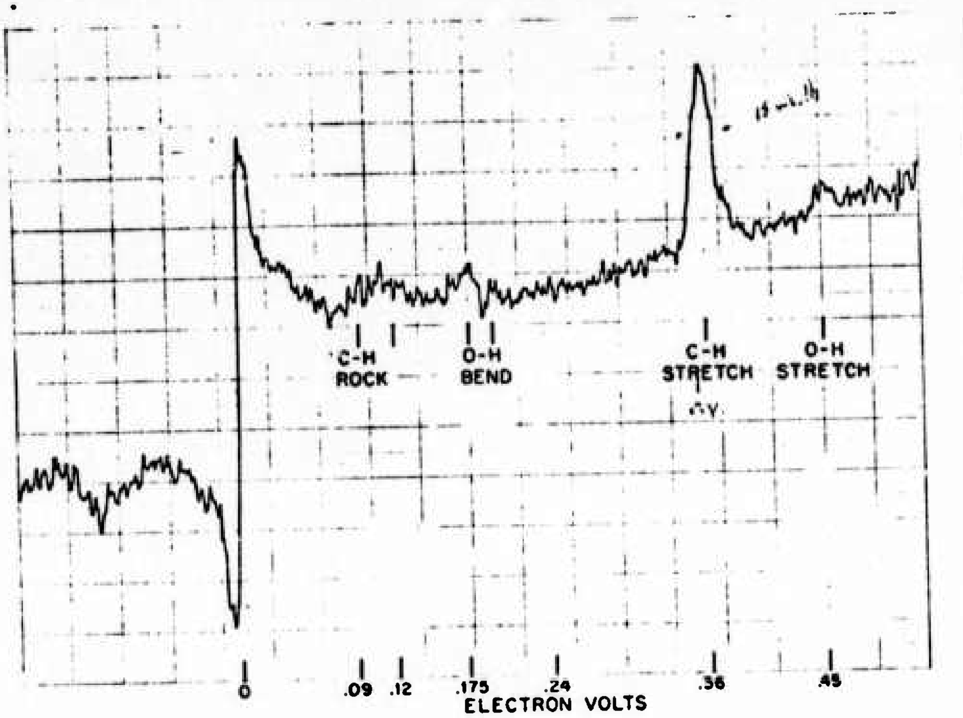

Fig. 4 Inelastic Tunneling in Aluminum - Aluminum Oxide - lead Junctions as Measured at 15 K.

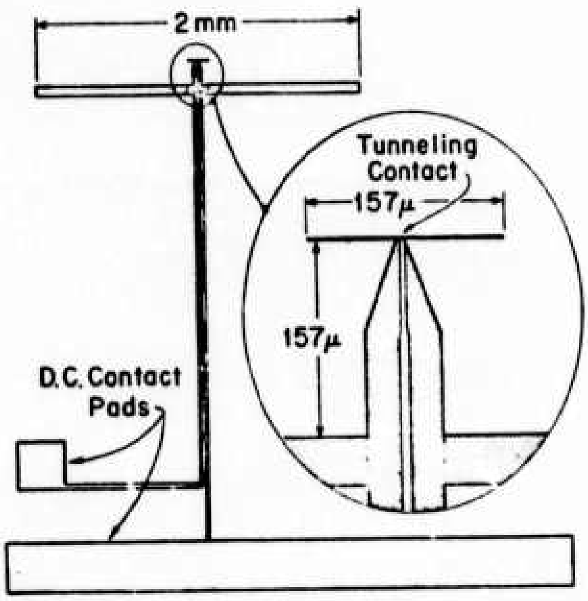

Fig. 5 Infrared and Microwave Dipoles with Tunneling Contact and DC Connections.

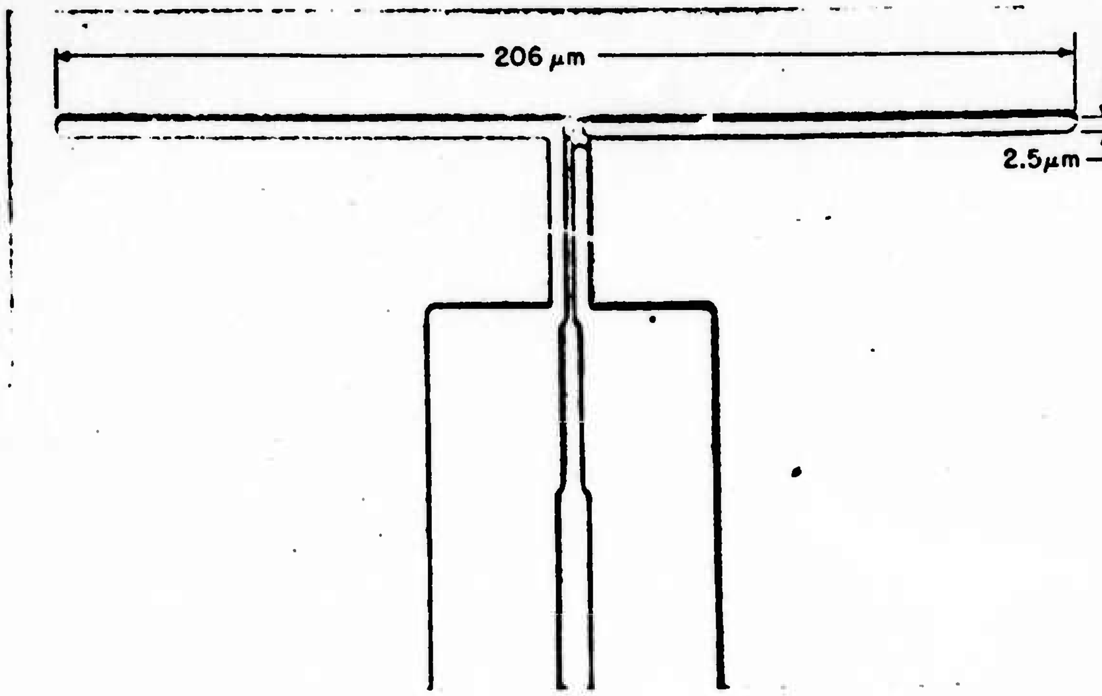

Fig. 6 $\frac{3\lambda}{2}$ Infrared Antenna. The Small Oval between the Dipole Halves is the Overlap Forming the Rectifying Junction.

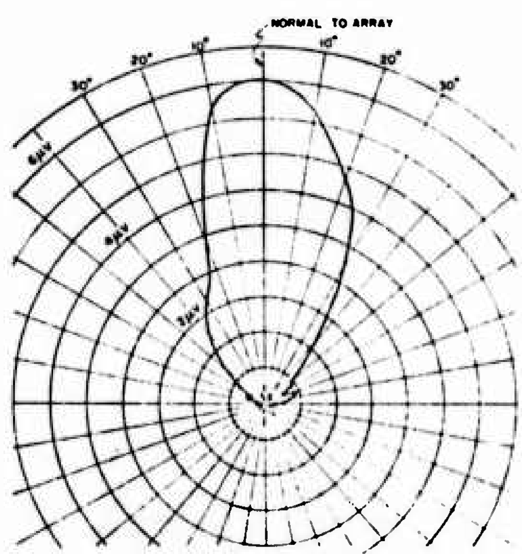

Fig. 7 Antenna Pattern of $\frac{3\lambda}{2}$ Dipole in Rotation about Dipole Feed Lines.